Correlation between variations of the surface concentration of atmospheric constituents in two industrial regions of Tatarstan

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This paper presents the studies of the correlation between variations of the surface concentrations of atmospheric constituents in two industrial regions of Tatarstan based on the experimental measurements by a network of atmospheric stations. Cross wavelet analysis is carried out for the series of the aerosol mass concentration, trace gases, and meteorological parameters. It is shown that atmospheric processes of synoptic scale modulate the spatial relation of the fields of atmospheric constituents and meteorological parameters in the surface layer. The spatial scales of synoptic variations of the concentrations of atmospheric constituents are estimated.

It has long been known that atmospheric waves of synoptic scale significantly affect the dynamics and energy of all atmospheric layers. Theory of these processes has been developed in Refs. 1 and 2. The role of large-scale processes in the global distribution of atmospheric constituents has been shown in Ref. 3. The investigations of planetary waves from long temperature and pressure series and their relations to the oceanic processes have been described in detail in Ref. 4. In Refs. 5 and 6 it has been shown that synoptic wave processes modulate mesoscale variations of both meteorological parameters and atmospheric constituents.

This paper is devoted to investigation of the effect of synoptic-scale wave processes on the spatial correlation between variations of the aerosol mass concentration, trace gases, and other atmospheric parameters in the surface atmospheric layer.

For this purpose, we used the long time series of various meteorological parameters and atmospheric constituents obtained at automated atmospheric monitoring stations in two industrial regions of Tatarstan. The observation sites are located in Zelenodolsk (54° N, 49°E) and Almetevsk (53°N, 51°E) separated by 260 km. Both of the stations measure simultaneously the surface concentrations of aerosol, carbon monoxide, nitrogen dioxide, other atmospheric trace gases, and meteorological parameters (temperature, wind speed and direction, relative humidity).[7] The instrumental parameters are summarized below in the Table.

Characteristics of the instruments measuring atmospheric constituents

Parameter	Measurement method	Resolution
CO	IR absorption	1 ppm
NO, NO_2	chemiluminescence	1 ppb/0.5 ppb
H_2S	UV fluorescence	1 ppb
SO_2	UV fluorescence	1 ppb
Aerosol	absorption of β-radiation (filter)	1 μg/m^3

The correlation between variations in the series of various atmospheric constituents and meteorological parameters at the spatially separated sites was studied using the cross-correlation and cross-wavelet analysis of time series of atmospheric parameters acquired at each site. The method of cross-correlation analysis consists in determination of the correlation coefficient between two time series $x(t)$ and $y(t + L)$ depending on the shift L between the series.[8] Since the series of atmospheric parameters are always nonstationary, local cross-correlation functions were constructed inside a moving 30-day time window from 38-month series of hourly mean values. It was found that the correlation function for all the studied parameters varies widely in time. The correlation peaks both at the zero shift between the series and at the shifts up to 20 days in different periods.

We have compared the cross sections of the local correlation function and the series of the surface pressure, temperature, and wind sped and direction. It turned out that the spatial correlation of the surface aerosol concentration, trace gases, and meteorological parameters at these sites depends on the local weather conditions. This conclusion was drawn based on the fact that the maximum correlation for all the parameters was observed in the periods, when the weather conditions at both sites were stable and similar – the wind field at the observation sites had the same direction, slowly varying during several days, and the temperature and pressure varied slightly.

When the wind at the observation sites had different directions (such a situation is usually observed during the pressure changes and strong temporal and spatial variations of the wind vector), the spatial correlation between all the atmospheric parameters, in particular, the concentrations of trace gases and aerosol, was weak. In addition, local correlation functions for all the studied parameters do not tend to zero with the increase of the shift

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between the series. They alternately decrease and increase as the shift is increased by several days. This indicates that wave processes of synoptic time scales contribute to the spatial correlation between atmospheric parameters.[8]

The apparatus of wavelet analysis well suits for analyzing variations of nonstationary processes. Wavelet transformation of time series, being a digital bandpass filter, allows us to study the changes in the spectrum of variations of the parameters in time. The technique for studying the series of geophysical parameters with the wavelet analysis has been described in Refs. 9 and 10. In Refs. 4, 6, and 11, this method was successfully used to estimate different-scale variations in the series of surface atmospheric parameters. The cross wavelet spectrum obtained with the aid of the Morlet parent function shows the relative level of relation between the periodic components of different temporal scales at different time. It is constructed in the following way. First wavelet transformation of each of the two time series $f(t)$ is performed with the use of the parent function $\psi(x)$:

$$Wf(x,a) = \frac{1}{a}\int_{-\infty}^{+\infty}\bar{\psi}\left(\frac{t-x}{a}\right)f(t)\mathrm{d}t. \quad (1)$$

Thus, two matrices, Wf_A and Wf_Z, are obtained. The absolute values of wavelet spectra characterize the contribution of periodic components to time series at any time. Then the cross-wavelet transformation is performed:

$$W = Wf_A Wf_Z^*, \quad (2)$$

where the asterisk denotes the complex conjugation of the wavelet transformation. The amplitude W (cross-wavelet spectrum) is used for estimation of the spatial correlation between variations in the time series of atmospheric parameters.

In the case of synchronous observations at two sites, it is possible to estimate the projections of the phase velocity onto the line connecting these sites and the spatial dimensions in the same projection from the equations:

$$\varphi = \frac{2\pi}{\lambda_x}x, \quad C_x = \frac{\lambda_x}{T}, \quad (3)$$

where φ is the value of the phase cross-wavelet spectrum for the time scale of variations T; x is the separation between two sites; λ_x is the wavelength; C_x is the phase velocity.[11] Since the wavelet transformation is analogous to application of the bandpass filter, features of the series depending on the local conditions and causing local-scale variations do not affect the determination of the parameters of synoptic processes.

The wavelet analysis of the series of the mass aerosol concentration, trace gases, and meteorological parameters at each observation site has been carried out. Figure 1 shows the examples of cross sections of the absolute values of wavelet transformation of the series of the mass aerosol concentration for the two sites in the characteristic period from April 1 to September 1 of 1997.

The cross section characterizes the time variation of the relative contribution of components of different synoptic scales to the studied signal, that is, at any time one can estimate the intensity of variations of all the time scales studied. The colored contours correspond to the excess of the 80% significance level by the intensity of the wavelet spectrum. It can be seen that for the period shown in Fig. 1 the prevailing processes in variations of the mass aerosol concentration at the both sites are harmonics with the periods of 5, 11, and 30 days. The same variations give maxima in the wavelet presentations of the temperature, relative humidity, and wind velocity series. For the atmospheric constituents, the intensity of these variations in Zelenodolsk and Almetevsk is different, which can be explained by the different mean level of air pollution at these sites. This result indicates that the level of atmospheric constituents is determined by the local sources at each site, while synoptic atmospheric processes cause modulation of the field of atmospheric constituents due to variation of meteorological parameters.

To study localization of the spatial correlation of time series in the frequency–time domain, cross-wavelet spectra of all the studied parameters were calculated for the period of 38 months.

The amplitude of the cross-wavelet spectrum with the Morlet basic function characterizes the level of relation between the series of these parameters in the two-dimensional frequency–time space. The phase part in the case of the Morlet wavelet contains the information about the shift in the time of maximum of the quasiperiodic variation of the corresponding time scale for one time series with respect to another.

Figure 2 shows the amplitudes of cross-wavelet spectra for the meteorological parameters and atmospheric constituents for the period since April 1 until September 1 of 1997. The values of the cross-wavelet spectrum are dimensionless. The scale shows only the relative level of correlation between the series. The colored contours correspond to the excess of the 80% significance level by the spectrum. It can be seen that the relation between the series of all the studied parameters is determined by harmonics with the time scales of 5, 11, and 30 days, that is, the same processes as those revealed in the spectra of each parameter. However, the maxima of cross-spectra are observed at different time for each parameter.

The study of the cross-wavelet spectra for the period of 38 months has shown that cross-wavelet spectrum exceeds the 80% significance level for characteristic synoptic periods from 3 to 20 days for all atmospheric constituents and meteorological parameters. The time scales of 30–50 days are significant in the cross spectrum of the concentrations of aerosol, nitrogen dioxide, sulfur dioxide, temperature, and wind velocity.

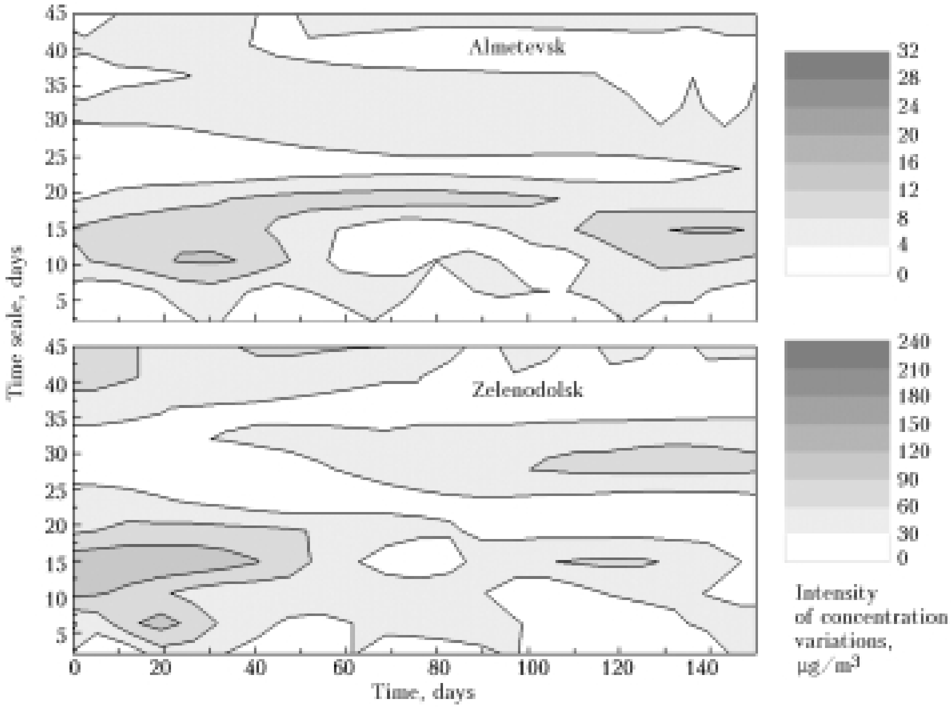
Almetevsk
Zelenodolsk
Time scale, days
Time, days
32
28
24
20
16
12
8
4
0
240
210
180
150
120
90
60
30
0
Intensity of concentration variations, μg/m3

Fig. 1.

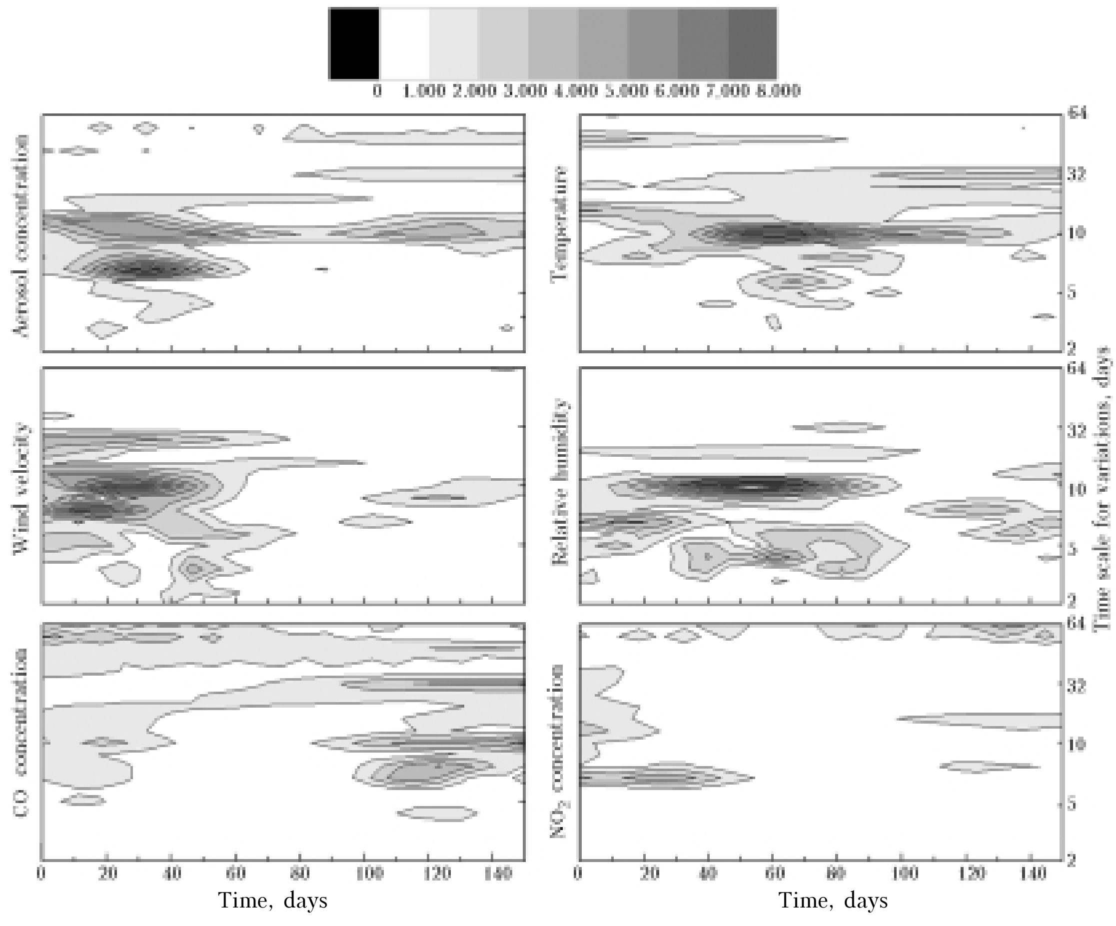
0 1.000 2.000 3.000 4.000 5.000 6.000 7.000 8.000
Aerosol concentration
Temperature
Wind velocity
Relative humidity
CO concentration
NO2 concentration
Time scale for variations, days
Time, days
Time, days

Fig. 2.

The analysis of the phase cross spectra allows us to estimate the phase velocities of motion of wave perturbations C_x and their spatial dimensions λ_x in projection onto the line connecting the two observation sites according to Eqs. (3). For estimation, we took the events of the excess of the 80% confidence interval by the cross spectrum and for these events estimated C_x and λ_x. The histograms of the horizontal phase velocities C_x and the histograms of the spatial scales λ_x of wave processes obtained from analysis of the series of the mass aerosol concentration are shown in Fig. 3.

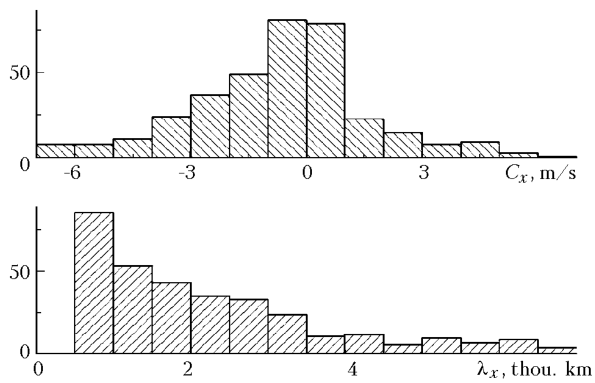

Fig. 3.

The comparison of analogous distributions obtained from the series of temperature, wind velocity, nitrogen dioxide concentration, and relative humidity by the Pearson criterion has shown that these distributions, within the 95% probability, belong to the same parent population, that is, variations of the studied parameters are determined by the same synoptic atmospheric processes.

We have estimated the spatial scales and the phase velocities of synoptic variations in the concentrations of atmospheric constituents. The most probable spatial scales of planetary waves vary from 1000 to 3000 km. The longer the wavelength, the greater the error in estimation of λ_x. The spatial dimensions up to 6000 km can be determined reliably. In the range from 6000 km and greater, the estimate only shows that the spatial scales of the wave process are much greater than the separation between the stations. The distributions of the phase velocities indicate that the most probable phase velocities of planetary processes are lower than 5 m/s. The waves with negative velocities propagate from the west to the east and are associated with the Rossby waves, while the perturbations with the positive velocities propagate from the east to the west and can be caused by manifestations of the Kelvin waves in the mid-latitudes.[2]

The results obtained indicate that atmospheric processes of synoptic scale modulate the spatial characteristics of correlation between the fields of atmospheric parameters, in particular, the concentrations of trace gases and aerosol in the surface layer.

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